# CODE DIVISION MULTIPLEXER USING DIRECT SEQUENCE SPREAD SPECTRUM SIGNAL PROCESSING

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to the following copending applications assigned to the assignee of this application: Application Ser. No. 592,670, filed on Mar. 23, 1984 and entitled CORRELATION DETECTORS FOR USE IN DIRECT SEQUENCE SPREAD SPECTRUM SIGNAL RECEIVER; now U.S. Pat. No. 4,561,089 Application Ser. No. 592,674, filed on Mar. 23, 1984 and entitled SYSTEM FOR IMPROVING SIGNAL-TO-NOISE RATIO IN A DIRECT SEQUENCE SPREAD SPECTRUM SIGNAL RECEIVER; Application Ser. No. 592,667, filed on Mar. 23, 1984 and entitled SYNCHRONIZATION SYSTEM FOR USE IN DIRECT SEQUENCE SPREAD SPECTRUM SIGNAL RECEIVER; now U.S. Pat. No. 4,567,588 and Application Ser. No. 592,668, filed on Mar. 23, 1984 and entitled TIMING SIGNAL CORRECTION SYSTEM FOR USE IN DIRECT SEQUENCE SPREAD SPECTRUM SIGNAL RECEIVER.

## TECHNICAL FIELD

The invention relates generally to code division multiplexing using direct sequence spread spectrum signal processing, and more particularly, toward signal processing to increase the number of transmitters multiplexed for a given code length.

## BACKGROUND ART

In a spread spectrum system, a transmitted signal is spread over a frequency band that is much wider than the minimum bandwidth required to transmit particular information. Whereas in other forms of modulation, such as amplitude modulation or frequency modulation, the transmission bandwidth is comparable to the bandwidth of the information itself, a spread spectrum system spreads an information bandwidth of, for example, only a few kilohertz over a band that is many megahertz wide, by modulating the information with a wide band encoding signal. Thus, an important characteristic distinguishing spread spectrum systems from other types of broad band transmission systems is that in spread spectrum signal processing, a signal other than the information being sent spreads the transmitted signal.

Spreading of the transmitted signal in typical spread spectrum systems is provided by (1) direct sequence modulation, (2) frequency hopping or (3) pulsed-FM or "chirp" modulation. In direct sequence modulation, a carrier is modulated by a digital code sequence whose bit rate is much higher than the information signal bandwidth. Frequency hopping involves shifting the carrier frequency in discrete increments in a pattern dictated by a code sequence, and in chirp modulation, the carrier is swept over a wide band during a given pulse interval. Other, less frequently used, carrier spreading techniques include time hopping, wherein transmission time, usually of a low duty cycle and short duration, is governed by a code sequence and time-frequency hopping wherein a code sequence determines both the transmitted frequency and the time of transmission.

Applications of spread spectrum systems are various, depending upon characteristics of the codes being employed for band spreading and other factors. In direct sequence spread spectrum systems, for example, where the code is a pseudo-random sequence, the composite signal acquires the characteristics of noise, making the transmission undiscernable to an eavesdropper who is not capable of decoding the transmission. Additional applications include navigation and ranging with a resolution depending upon the particular code rates and sequence lengths used. Reference is made to the textbook of R. C. Dixon, *Spread Spectrum Systems,* John Wiley and Sons, New York, 1976, especially chapter 9, for application details.

Direct sequence modulation involves modulation of a carrier by a code sequence of any one of several different formats, such as AM or FM, although biphase phase-shift keying is the most common. In biphase phase-shift keying (PSK), a balanced mixer whose inputs are a code sequence and an RF carrier controls the carrier to be transmitted with a first phase shift of X° when the code sequence is a "1" and with a second phase shift of $(180+X)°$ when the code sequence is a "0". Biphase phase-shift keyed modulation is advantageous over other forms because the carrier is suppressed in the transmission making the transmission more difficult to receive by conventional equipment and preserving more power to be applied to information, as opposed to the carrier, in the transmission. Characteristics of biphase phase-shift keying are given in Chapter 4 of the aforementioned Dixon text.

The type of code used for spreading the bandwidth of the transmission is preferably a linear code, particularly if message security is not required, and is a maximal code for best cross correlation characteristics. Maximal codes are, by definition, the longest code that could be generated by a given shift register or other delay element of a given length. In binary shift register sequence generators, the maximum length (ML) sequence that is capable of being generated by a shift register having n stages is $2^n-1$ bits. A shift register sequence generator is formed from a shift register with certain of the shift register stages fed back to other stages. The output bit stream has a length depending upon the number of stages of the register and feedback employed, before the sequence repeats. A shift register having five stages, for example, is capable of generating a 31 bit binary sequence (i.e. $2^5-1$), as its maximal length (ML) sequence. Shift register ML sequence generators having a large number of stages generate ML sequences that repeat so infrequently that the sequences appear to be random, acquiring the attributes of noise, and are difficult detect. Direct sequence systems are thus sometimes called "pseudo-noise" systems.

Properties of maximal sequences are summarized in Section 3.1 of Dixon and feedback connections for maximal code generators from 3 to 100 stages are listed in Table 3.6 of the Dixon text. For a 1023 bit code, corresponding to a shift register having 10 stages with maximal length feedback, there are 512 "1"s and 511 "0"s; the difference is 1. Whereas the relative positions of "1"s and "0"s vary among ML code sequences, the number of "1"s and the number of "0"s in each maximal length sequence are constant for identical ML length sequences.

Because the difference between the number of "1"s and the number of "0"s in any maximal length sequence is unity, autocorrelation of a maximal linear code, which is a bit by bit comparison of the sequence with a phase shifted replica of itself, has a value of $-1$, except